Is it possible to mitigate greenhouse gas emissions from agricultural soil by introduction of temporary grassland into cropping cycles ?

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ABSTRACT

Agriculture contributes strongly to greenhouse gas emissions, in particular through the emission of N_2O. In this study, we investigated the intensity of such emissions from French grassland soils under contrasting management by combining an experimental and a modelling approach. The objectives of this study were to measure and estimate N_2O emissions and C storage at field scale and to assess the effects of grassland management on the processes determining soil organic C-storage and greenhouse gas emissions. Our conceptual approach included modelling of N_2O emissions from grasslands and the investigation of the controls of N_2O emissions by means of the characterisation of soil organic matter (SOM) composition as well as microbial communities. We continuously measured greenhouse gas emissions at long term grassland experiments in France. Moreover, we investigated the nature of SOM and the abundance and the activities of microbial communities in the soils from the different grassland managements.

Our data indicated that grassland management practices, such as grazing, mowing, animal density, fertilisation and length of grassland periods, influenced soil C-storage, SOM composition and microbial abundance and activity. Such effects may be observed as legacy effects even after several years of cropping. Greenhouse gas emissions, in particular those of N_2O, are strongly influenced by the management practices and their effects on SOM and soil microbial parameters. As they are contrasting, a compromise has to be found in order to ensure optimal ecosystem services of grassland systems.

Keywords: temporary grassland, soil organic matter composition, microbiology, greenhouse gaz emissions

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Grassland systems are important in terms of carbon storage and mitigation of greenhouse gas emissions, in particular those of CO_2 and N_2O. Their introductions into cropping cycles could be a solution to maintain and increase the carbon storage potential of agroecosystems (Lemaire et al., 2015). However, there are two important knowledge gaps: (1) a big uncertainty concerning the quantification of C and N fluxes in grassland systems under contrasting management and (2) a lack of evaluation of practices to mitigate greenhouse gas emissions from these soils. This calls for integrated modelling of greenhouse gas emissions and carbon storage, while taking into consideration soil parameters and ecosystem services provided by these systems. For this study, we proposed to reduce uncertainties concerning the prediction of greenhouse gas emissions and soil C and N storage using a long term experimental site with grasslands under contrasting management. Temporary grassland management included mowing, presence or absence of N fertilisation and different duration of grassland phase. The legacy effect of grassland management on SOM and microbial parameters was investigated at the same sites during field campaign aiming to couple N_2O emission measurements with soil organic matter characteristics and microbial parameters. The aims of the study were (1) to determine linkages between microbial characteristics, soil organic matter status and greenhouse gas fluxes and (2) to assess the effect of grassland management practices on C storage, SOM, microbial parameters and N_2O emissions of agricultural soils.

METHODOLOGY

For the modelling exercise we used two models, CERES-EGC and PaSim, and continuous data from a long term observatory for environmental research including pasture,mowed grasslands and croplands. First, we ran the crop model CERES-EGC and the grassland model PaSim in their spatialized versions to obtain European wide greenhouse gas emission maps for agricultural soils at a resolution of 770 km². To simulate greenhouse gas emissions from soils in rotation with crop and temperate grasslands we finalise the development of the FarmSim model resulting from the coupling of the above mentioned models. This model was used to validate and investigate the processes leading to greenhouse gas emissions under different management; at this aim we used the data from the forage and grasslands observatory, from 2005 to 2011 and reproduced continuous soil measured data as water, N and C with the new model. In addition, at this site we carried out a field experiment and investigated simultaneously greenhouse gas emissions, soil organic matter stocks, composition as well as activity and abundance of microbial communities. The treatments included in the experiment were (i) 9-year permanent grassland and (ii) permanent cropland, (iii) 3-year fertilised temporary grassland, (iv) 6-year fertilised and (v) unfertilised temporary grassland. When temporary grassland soils had experienced a 3-year crop cycle, the first 10 cm of soils were sampled in order to investigate the legacy effects of grassland duration (3 or 6 years) and fertilisation (with or without N). Soil organic matter stocks were determined and SOM composition was analysed for lignin as well as carbohydrate content and composition, and microbial communities were characterised with a genetic approach, investigating the genes involved in N_2O emissions.

RESULTS

Our data indicated that the uncertainties concerning the evolution of N_2O emissions through all models are high, due to the poor reproduction of measured N_2O data. In fact, by using the coupled model FarmSim, the simulation of a 6-year fertilised temporary grassland followed by 3 years of crops, resulted with RMSE in the order of 3.9 g N_2O ha^{-1} d^{-1} and a modelling efficiency (EF) of -0.89; the simulation of a 9-year permanent grassland resulted with RMSE and EF of 16.5 N_2O ha^{-1} d^{-1} and 0.01, respectively. Our study intended to address these shortcomings in models by the detailed investigation of soil parameters driving N_2O emissions and the identification of new processes to be incorporated in the models. Our experimental data about soil organic matter sampled in the different treatments, showed contrasting carbon stocks. Permanent grassland presented after 9 years significantly higher C stocks than permanent cropland but also showed much higher N_2O emissions. Temporary grassland management induced legacy effects, which persisted after the 3-year cropland phase. Accordingly, carbon stocks and N_2O emissions were observed to decrease without N fertilisation during a 6-year temporary grassland as compared to continuous cropland (Fig. 1). Temporary grassland duration was less important with regards to legacy effects concerning C storage and N_2O emissions.

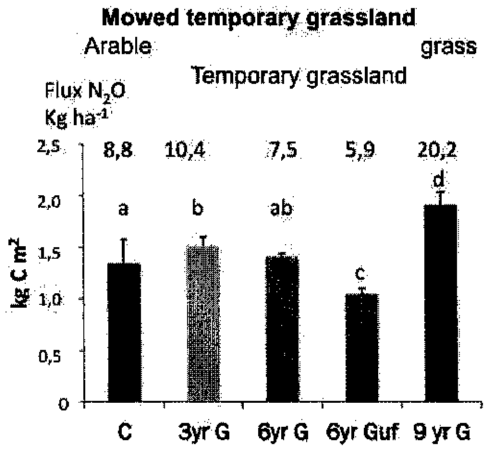

Fig. 1: Carbon storage in soils from the study site, including 9 years continuous crop (C), 9 years continuous grassland (9yrG), and temporary grasslands after 3 years of crop, which include 3 years fertilized grassland (3yrG), 6 years fertilized grassland (6yrG) and 6 years of unfertilized grassland (6yrGuf)

The legacy effect of grasslands on SOM composition was characterised by higher concentrations of fresh plant-derived compounds as compared to cropland SOM. Microbial communities of grassland soils involved in N_2O emissions were in turn less dependent on labile C input as compared to those of cropland soils. These parameters showed a linear correlation with grassland duration. Principal component analyses of parameters characterising soil microbial communities and soil organic matter composition showed separation of permanent grassland and cropland. Fertilised temporary grasslands were in between both controls if its duration was of 6 years, while 3 years fertilised grassland was not different from cropland. Unfertilised temporary grasslands were separated from all others.

DISCUSSION

According to our data, it seems that while grasslands are beneficial for increasing C storage, at the same time they increase N_2O emissions, which is an adverse effect with regards to climate change mitigation. The soil inherent mechanisms leading to such emissions may be related to the high input of fresh plant-derived SOM, which stimulates the activity of microorganisms involved in denitrification. Indeed, permanent soil cover and high root litter input may lead to the accumulation of high amounts of particulate organic matter (Rumpel et al., 2015). In addition to absence of dependence on labile C, N_2O emissions may also be due to the N fertilisers used needed to maintain grassland productivity. This practice is necessary, as unfertilised grasslands are unproductive and also store less soil carbon.

CONCLUSIONS

We investigated the legacy effect of temporary grassland management on N_2O emissions, composition and activity of microbial communities and soil organic matter characteristics. Our data showed that modelling of such emissions in temporary grassland soils need to be improved, as the existing models even after their coupling did not correctly reproduce the measured emissions. Our field experiment indicated that there is a close relationship between SOM parameters and N_2O emissions, which is influenced by grassland management and leads to legacy effects, which persist after 3 years of continuous crop. It seems that a compromise has to be found concerning grassland management in order to optimise ecosystem services.

REFERENCES

Lemaire, G., Gastal, F., Franzluebbers, A. & Chabbi, A. 2015. Grassland–Cropping Rotations: An Avenue for Agricultural Diversification to Reconcile High Production with Environmental Quality. *Environ Management*, 56: 1065–1077. doi: 10.1007/s00267-015-0561-6

Rumpel, C., Crème, A., Ngo, P.T., Valesquez, G., Mora, M.L. & Chabbi, A. 2015. The impact of grassland management on biogeochemical cycles involving carbon, nitrogen and phosphorus. *Journal of Soil Science and Plant Nutrition*, 15(2): 353-371.